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THE NEWEST TELESCOPE.

BY PROF. C. A. YOUNG.

Many of our readers doubtless remember the great telescope which loomed up so imposingly at the north end of the central aisle in the main building of the Chicago exhibition, giving a most impressive idea of the magnitude and power of the astronomical artillery with which our modern science assails the heavens and aims to penetrate their mysteries.

One felt justly some stirrings of patriotic pride in the noble instrument as a magnificent triumph of American art, and a fresh example of the enlightened liberality of our men of wealth and affairs. In the foundation and equipment of the great observatory which is to bear his name, Mr. Yerkes has established for himself a place upon the roll of honor along with Lick, Carnegie and others, who by their munificent gifts to learning, science and art have secured a perpetual and grateful remembrance.

The instrument itself, except in one item, is purely American. The mounting and machinery are by Warner & Swasey, of Cleveland, the same firm that made the mounting of the great telescopes in the observatories at Washington and Mt. Hamilton, as well as many smaller ones, and it is not too much to say that in design and workmanship their instruments do not suffer in comparison with the best of foreign make, while in "handiness" they are distinctly superior. There is no longer any necessity for us to go abroad for astronomical instruments which are fully up to the highest standards.

The forty-inch object glass of the Yerkes telescope is by Alvan G. Clark, the sole survivor of the famous firm of Alvan Clark & Sons, which, during the last twenty-five years, has sent out as many great telescope lenses as all other firms together, among them the thirty-inch objective of the great instrument at Pulkowa, and the still larger thirty-six inch lens of the Lick Observatory, which, since 1887, has maintained an unapproachable supremacy until displaced by this younger brother.*

The one non-American feature in the Yerkes telescope is an important one; the glass from which the lenses were made is foreign, by Mantois, of Paris, the only firm in the world which at present can furnish discs of the size and quality required. A few attempts have been made in this country to introduce the manufacture of optical glass, but thus far with very little success, and our opticians are still compelled to send abroad for their material. It is to be hoped that before very long this disability will disappear, but the difficulties of the manufacture are great, and the demand so limited that the prospect of profit is not encouraging.

To the casual observer at Chicago the instrument seemed practically complete, though really hardly half finished. At that time the object-glass, to which everything else is subordinate, was little more than roughed out, and many of the more delicate portions of the mounting were in the same condition or wholly wanting. It has taken two years of unremitting labor to perfect what was incomplete and to add the indispensable accessories with which the eye and the hand of the observer are most directly to operate, such as the eyepieces, micrometers, spectroscopes, and other minor but essential parts.

Now at last the instrument is finished, and only awaits the completion of the observatory which is to shelter it. The object glass, forty inches in diameter and by far the largest ever made, was finally examined and accepted last October, and pronounced by the committee of experts "entirely satisfactory," fulfilling all the conditions of the contract, and responding to every test at least as well as the best of all the other large lenses which have thus far issued from the hands of its makers, fully their equal in the excellence of its figure and corrections, and of course markedly superior to them all in its light-collecting power. It gathers three times as much light as the 23-inch instrument at Princeton; two and three-eighths as much as the 26-inch telescopes at Washington and Charlottesville; one and four-fifths as much as the 30-inch at Pulkowa; and 23 per cent. more than the gigantic, and hitherto unrivalled, 36-inch telescope of the Lick observatory. Possibly in this one quality of "light," the six-foot reflector of Lord Rosse, and the later five-foot reflector of Mr. Common, might compete with or even surpass it, but as an instrument for seeing things it is doubtful whether either of them could hold its own with even the smallest of the instruments named above, because of the reflector's inherent inferiority in distinctness of definition. This is due to the disastrous effects upon its performance which are produced by the slightest differences of temperature in different parts of its massive mirror, and by the infinitesimal flexures consequent on the changes of position required in following a star for any length of time. From these difficulties a lens is practically free.

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* It is difficult to realize the progress of the last sixty years in the matter of telescope-making. In 1836 the two most powerful refracting telescopes in the world were the 9½ inch instrument at Dorpat, and the 11-inch at Munich. In the United States the largest instrument was the 5-inch Dollond telescope of Yale College, which in 1840 was supplanted by the 6-inch Munich telescope at the Philadelphia High School. Before 1850 several other German instruments were imported, the most notable being the 11-inch telescope at Cincinnati, the 9½-inch at Washington, and the 15-inch at Cambridge, which, with its twin at Pulkowa (dating from 1839), for many years shared the honor of being the largest in existence. It was in 1846 that Alvan Clark, Sr., made his first telescope, and since 1850 very few telescopes of any importance have been imported, while a number of Clark's lenses have gone abroad. Fitz and Spencer also made a number of large telescopes between 1850 and 1870, and at present Brashear, of Pittsburg, is vigorously competing with the Clarks themselves in the size and excellence of his object-glasses.

Still it must not be supposed that the new object-glass is ideally perfect. The best possible two-lens objective, made from such materials as are at present obtainable in discs of any considerable size, sins grievously in not bringing the light rays of different color to any single focus—its "achromatism" is far from absolute. In the case of this 40-inch lens the greenish yellow rays come together at a point nearly six inches nearer to the lens than do the violet; so that the image of a bright star is surrounded by a strong purple halo, which is usually pronounced "perfectly lovely" by a female tyro, but is an abomination to the astronomer. It is particularly annoying in spectroscopic or photographic work, and where such work is specially in hand the fact that the reflector is entirely free from it, treating rays of every color impartially in the matter of focus, goes far to condone its peculiar weaknesses.

This imperfection of the ordinary object-glass is in no respect the fault of the optician, but lies in the material itself. Experiments, subsidized by the German government, have been going on at Jena during the last dozen years for the purpose of remedying the evil, with special reference, however, to the improvement of the microscope. In that, complete success has been reached, and there is much reason to hope that before very long it may become possible to obtain varieties of glass which in combination will give satisfactory achromatism, and in discs of sufficient size to permit the construction of large telescopic object-glasses as perfect in their way as the new "apochromatic" microscope objectives are in theirs. It will be a step almost as important as was Dollond's invention of the present achromatic lens. Thus far, however, no great success has been attained with telescopes of any considerable magnitude, though an English firm is now offering to make three-lens objectives up to twenty inches in diameter, which are advertised as practically perfect in their achromatism. A six-inch lens of this construction has been very favorably reported on by Dr. Roberts, and it is perhaps not impossible that a new era of telescope-making may open with the new century.

To return from this digression: The crown-glass lens of the great object-glass is double convex, about two and a half inches thick in the middle, though only three-quarters of an inch at the edge, and weighs two hundred pounds. The flint-glass lens is nearly plano-concave, with the flat surface inside, *i. e.*, nearest the eye end of the telescope.

It is about two inches thick at the edge and an inch and a quarter in the centre, and weighs over three hundred pounds. The two lenses are separated by a space of eight and three-eighths inches, and are set upon aluminium bearings in a steel cell itself weighing five hundred pounds; so that the whole mass which has to be carried at the upper end of the telescope tube is nearly half a ton.

The focal length of the object-glass, or rather the distance from the inner surface of the flint-lens to the place where the image of a star is formed (which is not quite the same thing) is stated by Mr. Clark * to be sixty-one feet; so that the total length of the instrument will be between sixty-two and sixty-three feet. This will be increased by at least seven or eight feet when the spectroscope is in place. The image of the sun or moon formed in the focal plane will be nearly seven inches in diameter.

The magnifying power of the telescope can be made by mere

*** For much of the information embodied in this article I am indebted to the courtesy of Mr. Clark, of Warner and Swasey, and especially of Professor Hale, to all of whom my warmest thanks are due.**

change of eyepieces to range anywhere from about two hundred to four thousand. This highest power will bring the moon, optically, to within just about sixty miles from the observer's eye; but he will see her surface much more clearly than one can see the details of a terrestrial landscape at that distance from the top of a mountain, because in the latter case the surface is viewed very obliquely, and through the densest and haziest portion of our atmosphere.

Any lunar object five or six hundred feet square would be distinctly visible—a building, for instance, as large as the capitol at Washington. A line much narrower than this, especially if it differed much in color or brightness from the background, would at once attract attention, and so would any brilliant object, even if no larger or brighter than an ordinary arc light.

With very high powers the field of view will be very narrow, hardly including the whole of even such a crater as Tycho or Copernicus ; nor can such powers be used advantageously except under very unusual atmospheric conditions: powers between five hundred and two thousand will ordinarily be most useful.

When directed to the zenith the great eye of the instrument will be seventy-five feet above the normal level of the floor, which, however, can be raised and lowered at pleasure through a range of twenty-two feet, to bring the eyepiece within convenient reach of the observer. The centre of motion, or the point where the two axes intersect, is forty-three feet above the floor.

The mass of the whole machine, including its cast-iron pedestal, is seventy-five tons, of which the movable portions—the axis, circles, counterpoises, tube, etc.—weigh thirty. The great tube itself alone weighs six tons ; it is sixty-one feet long, and fifty-two inches in diameter at the middle, tapering slightly to each end. It is made of sheet steel, the thickness of which was carefully determined in advance by computation, to give the requisite strength with the minimum weight, and varies gradually from about a quarter of an inch at the middle to an eighth of an inch at the extremities. The whole is so beautifully poised on its anti-friction bearings that a pressure of less than twenty pounds moves it freely. The driving clock is so delicate, and at the same time so powerful, that the enormous tube, once pointed at a star, will follow it exactly for hours, keeping it precisely upon the cross wires all the time, undisturbed by any ordinary effects of varying friction, or gusts of wind, or inadvertent pushes of the observer.

The skillful makers have embodied in the mechanism many new and ingenious devices which greatly facilitate the observer's control of the gigantic instrument—in fact, a single man, even without an assistant, can point and manage it quite as easily, if not quite as rapidly, as he could one of the old fashioned twelve or fifteen-inch equatorials. Electricity is used to a great extent, not only for the illumination of the circles and micrometers, but for controlling the clock-work and automatically re-winding it when necessary, and for actuating the quick and slow motions by which the telescope is directed upon an object. Hitherto, in the more modern instruments at least, the slow motions have been managed by long, jointed handles, brought down along the tube to the eye end, and transmitting the power of the observer's hand around various corners through a complicated train of wheel work to the screw that was to be turned—a mechanism subject to much "lost motion" and easy derangement. In the new system, little electric motors are attached directly to the different slow motion screws, and the conducting wires are led to various convenient points, so that the observer himself at the eyepiece, or an assistant on the gallery that surrounds the top of the pedestal, or a person standing anywhere on the floor, can control everything by the mere touch of a finger or the sliding of a switch. The old mechanism has not been entirely discarded, however, but has been retained as a measure of precaution in addition to the new, in order that the instrument may never be disabled at some critical moment by the failure of the dynamo or storage battery, or the breaking of a wire.

The great ninety-foot rotating dome which is to shelter the instrument, is relatively as gigantic as the instrument itself, larger by far than anything of the kind ever before constructed. (The domes at Nice and the Lick observatory, which rank next in magnitude, are each about seventy-five feet in diameter.)

It was built by Warner and Swasey—of steel, like the telescope tube itself—and although it weighs nearly a hundred and fifty tons, it will doubtless be turned and handled with perfect ease by the machinery provided for the purpose. It is not yet in place, but is ready to be erected as soon as the masonry tower which is to carry it is completed, and that was reported as "nearly finished" early in November. It is likely, however, that the severity of the Wisconsin winter will postpone the actual mounting of the dome and instrument until spring, and the formal opening of the observatory is hardly likely to take place much before the end of the summer.

The observatory, though belonging to the University of Chicago, is not in the city, but is situated on the northern shore of Lake Geneva, about seventy-five miles to the northwest and a few miles beyond the State line. It is a hundred and eighty feet above the water, in the midst of a large tract of land that has been given for the purpose. The building has the form of a Roman cross, the longer arm, about four hundred feet over all, running east and west, with the great dome at its western extremity and the meridian room at the eastern. The cross arm, or transept, carries a smaller tower and dome at each end ; in the northern of the two will be mounted the twelve-inch instrument (fitted for both visual and photographic work), which is now in the Kenwood Observatory of Professor Hale, the Director-elect of the new establishment. In the southern dome a sixteen-inch telescope by Brashear (who also made the Kenwood instrument) will be placed. Of course the reader understands that, as a rule, any work that is well within the reach of a moderate-sized instrument can be done by it much more conveniently and rapidly than by a very large one : a cannon is a poor weapon for snipe shooting, and an observatory equipped with one great telescope only is much like a warship with no rapid-fire guns.

The transept is occupied by a long heliostat gallery for certain solar work, and the main building, between the great tower and the meridian room, is taken up with rooms for the observers, offices, computing rooms, library, lecture room, photographic rooms, physical laboratory, etc.

The meridian room is planned to receive at some time a first-class meridian circle, but for the present will be occupied only by a small transit instrument, since the work of the establishment, for a while at least, will be directed almost entirely along the lines of the "New Astronomy."

A small building at some distance from the observatory contains the boilers, engines, dynamos, and workshops for the construction and repair of instruments.

The selection of a site appears to be the best possible under the circumstances; far enough from the city to avoid its smoke and dust, and the glare of its electric lights, as well as the interruption of too numerous curious visitors; and yet near enough to permit of quick and easy communication. The atmospheric conditions are undoubtedly better than nearer Lake Michigan, and are probably fully as good as those that prevail at the majority of American observatories. But "the Prince of the Power of the Air" is everywhere the most malignant enemy of the observational astronomer, and it remains to be seen just how serious are the limitations which his malice will impose in this case. We can hardly hope for the exceptional excellence of the "seeing" which prevails at Mt. Hamilton, Nice, and Arequipa, but there is no reason to look for anything exceptionally bad.

And now, of course, comes the question of utility. What is the real use of the whole great expenditure? It may be admitted at once that, so far as now appears, the advancement of astronomy will contribute *directly* very little to the material welfare of mankind. It is an "unselfish science," not a "bread and butter" one, and has no such immediate bearing upon human sustenance and comfort as most of the other physical sciences. Its benefits are for the most part purely intellectual; in the widening of the range of thought; in the stimulus of grappling with problems that tax to the utmost our highest faculties; in the power that knowledge fairly won always brings to its possessor,—by the process of acquisition even more than by its actual possession; for usually it happens that the struggle of attainment counts for more in the development of the individual and of the human race than the victory and the prize it brings.

But granting the value of astronomical research and progress, the further question arises whether in the real interest of the science such expenditure for new observatories and gigantic telescopes is justifiable; and there are some who deny it, even among those whose opinion is entitled to respectful consideration. They are more interested in other, older, and, in their view, more important branches of the science than those to which the new institution is to be devoted, and they feel a very natural jealousy at what seems to them neglect of the fundamental investigations of mathematical astronomy in favor of the apparently easier, more showy and more popular work of mere telescopic, spectroscopic and physical observation.

The more reasonable view, however, is unquestionably that both lines of work are valuable, and essential to the growth and perfection of the science; neither should be neglected. It may be true that there can never be any astronomical work of a higher order than that of Newton, Laplace, Gauss, Bessel and Leverrier, not to mention the great names of others who still live, and keep up gloriously the old traditions. But a new era has opened, and now with our present instruments and methods we are able to attack problems and undertake researches which were utterly impossible twenty-five years ago. As Miss Clerke tersely expreses it: "Modern sidereal astronomy *lives on light.* Large telescopic apertures are a *sine quâ non* for its growth and activity." Whether we work with eye or photographic plate, with spectroscope or bolometer, the cry is still "more light," whenever we attempt to carry our studies beyond the scanty material furnished by the first hundred or so of the brightest stars and nebulæ.

There is reason therefore to hope, and to expect, that the new observatory will soon justify its foundation by the rapid accumulation of valuable data which are beyond the reach of smaller instruments, and by the deduction of important and significant results: perhaps also, but by no means certainly, by some brilliant and sensational discovery.

Its work, according to the provisional programme already laid out by the Director, will be various. During the day the great telescope will be mainly used in the study of the sun, chiefly spectroscopic, the observations being made both visually and photographically; to some extent also by the bolometer, with which it is hoped to reach the solar corona somewhat as the prominences are reached by the ordinary spectroscopic method. In work of this sort, the great size of the image of the sun formed by the forty-inch object-glass gives an immense advantage, and it is worth noting that in the *daytime* the atmospheric conditions at the Yerkes observatory will probably be much better than they are at Mt. Hamilton, though at night the case is different.

Two nights in the week are reserved for spectroscopic studies of stars and nebulæ, in which a wide field is opening, especially as regards the spectroscopy of variable stars and the motions of the sidereal system. Other nights will be devoted to visual observations of planets, comets, etc., and others to the measurement of the more difficult double stars, work for which Messrs. Burnham and Barnard, formerly on the staff of the Lick observatory, have already been secured.

It seems almost a pity that no provision has been made to utilize the power of the great instrument in stellar photography; but this would require a heavy expense for an additional "photographic corrector" to be put on outside of the object-glass, and its use would occupy the instrument at times when it could ill be spared from other work. The subject is being well followed up, too, at several other observatories. At some future time it is quite possible that the deficiency may be supplied. It is mainly a question of money.

The smaller instruments will find an abundance of work that is fairly within their reach, and of course the computing rooms and the physical laboratory will be kept more than busy in the reduction of the material accumulated by the observations, and the researches required for their interpretation.

C. A. Young.